ATLAS
A FACILITY FOR HIGH ENERGY DENSITY PHYSICS RESEARCH AT LOS ALAMOS NATIONAL LABORATORY

W. M. Parsons, W. A. Reass, J. R. Griego, D. W. Bowman,
C. Thompson, R. F. Gribble, J. S. Shlachter, C. A. Ekdahl, P. D. Goldstone, and S. M. Younger

Los Alamos National Laboratory
Los Alamos, NM. 87545

Abstract

Atlas is a facility designed to perform high energy-density experiments in support of weapon-physics and basic-research programs at Los Alamos. For hydrodynamic experiments, it will be capable of achieving pressures exceeding 30 Mbar in <cm^3 volumes. For radiation transport experiments, it will be capable of producing greater than 3 MJ of soft x-rays.

The capacitor bank design consists of a 36-MJ array of 600-kV Marx modules. The system is designed to deliver a peak current of 20 - 25 MA with a 2 - 3 μs rise time. The capacitor bank is resistively damped to limit fault currents and capacitor voltage reversal. Both oil- and air-insulated Marx module designs are currently being evaluated. An experimental program for testing both prototype components and the air-insulated concept is currently underway.

The capacitor bank design contains 300 closing switches. The primary candidate is a modified version of a Maxwell railgap switch originally designed for the DNA-ACE machines. An alternative candidate is a low-inductance surface-discharge switch. Because of the large number of switches in the system, individual switch prefire rates are required to be less than 10^{-4} to protect the high-value loads and targets.

Experiments are underway to determine if switch-prefire probability can be reduced by increased capacitor charging rates. A pulse-charging system is described which is capable of charging the 36-MJ capacitor bank to full voltage in 40 milliseconds. This system would use the LANL 1430-MVA generator and a 50-MJ set of intermediate energy-storage inductors. Charging the capacitor bank with a large rectifier connected directly to the generator is another option, and would produce charging times in the 1 - 6 s range. Conventional rectifiers and grid power would be used for charging times > 6 seconds.

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Introduction

The Atlas project within the High Energy Density Physics (HEDP) Program at LANL is an element of a strategic response to the changing requirements being placed on Department of Energy (DOE) Defense Programs (DP). These requirements include the Presidential call[1] to ensure the safety and reliability of U.S. nuclear weapons without underground nuclear testing. DOE and the national laboratories will continue their responsibility for maintenance, surety, and reliability of the nation's remaining stockpile. This stockpile stewardship has been identified as a key strategic focus area within DOE/National Security strategic planning. The HEDP Program requires three distinct environments to successfully support the necessary weapons-related experiments. These three classes of capability include pulsed-power, high-energy lasers, and ultra-high-intensity lasers. Both the pulsed-power and laser capabilities are called out in the DOE/DP Stockpile Stewardship and Management Program[2].

A significant pulsed-power capability currently exists at LANL: the Pegasus II 4.3-MJ capacitor bank[3], and the Procyon high-explosive-driven, pulsed-power generator[4]. This capability uses a technology approach (long-pulse, 0.3 - 3 μs pulsed power) both optimized and cost-effective for the needs of HEDP weapon physics. However, Pegasus and Procyon do not have sufficient energy to reach the conditions required for adequate support of weapon physics. To provide this capability requires construction of the Atlas facility which will serve as a principal experimental pulsed-power resource for HEDP. Table I shows a comparison of baseline parameters and experimental capabilities for Pegasus II and Atlas.

Table I
Comparison of Baseline Parameters and Experimental Capabilities

Baseline parameters	**Pegasus II**	**Atlas**
Current to target	12 MA	20 - 25 MA
Direct-drive pulse length	6 μs	2 - 3 μs
Stored energy	4.3 MJ	36 MJ
Capacitance	864 μf	200 μf
Output voltage (90% charge)	90 kV	540 kV
Inductance (nominal)	30 nH	30 nH
Experimental capabilities		
Hydrodynamic (adiabatic compression)		
Volume > 1 megabar	2 cm^3	12 cm^3
Volume > 10 megabar	(n/a)	1 cm^3
Volume > 1 megagauss	40 cm^3	250 cm^3
Radiation		
Implosion kinetic energy, maximum	0.5 MJ	> 3 MJ
Soft x-ray output (with switch)	0.2 MJ	3 - 4 MJ
Peak temperature (with switch)	< 100 eV	130 - 200 eV

The primary mission for Atlas will be to drive hydrodynamic experiments. For these experiments, the pressure generated in the target is an important figure of merit. Pressure capabilities are inversely related to target volumes with the highest pressures generated by collisions of concentric cylinders or spheres. Atlas could also, in principle, be used as a soft x-ray source. Recent tests[5] using Procyon indicate that, by directly imploding thin foils, Atlas could easily produce radiation pulses exceeding 1 MJ at temperatures approaching 100 eV. Moreover, radiation temperatures could be significantly increased by using a plasma flow switch (PFS). As an integral part of the experimental package, the PFS could compress the liner-current rise time from 2 - 3 μs to less than 0.5 μs. For each of these cases, the inductance change of the load as a function of time can be expressed as an impedance. Table II lists the impedances for each of these three loads.

Table II
Impedance of Typical Loads

Load Type	Impedance (dL/dt)
Hydrodynamic	~ 1 mΩ
X-ray, PFS	> 3 mΩ
X-ray, direct drive	> 10 mΩ

Atlas will certainly become a useful tool for basic research[6]. The facility will be capable of subjecting $<$cm^3 volumes of a sample material to pressures exceeding 30 Mb and producing magnetic fields in excess of 1000 T. These features will allow experimenters useful opportunities to explore the physics of matter under these extreme conditions.

Design Requirements

The Atlas machine must be flexible in order to accommodate a wide variety of weapon-physics and basic-research experiments. To produce the types of conditions required for these experiments, Atlas must meet the requirements described below.

The machine must be able to produce a peak current of 20 - 25 MA with a rise time of 2 – 3 μs. The radial and axial diagnostic access around the target chamber must be maximized. Due to the complexity and cost of weapon-physics experiments, system reliability must be greater than 95%. The machine must be designed to perform experiments at a maximum rate of twice weekly with a useful lifetime of at least 20 years. Because the system will require rapid turnaround to achieve the required shot rate, modularity and ease of maintenance are essential design criteria. Finally, the facility should include full support services for users including data analysis, film processing, and planning and coordination areas. An artist's conception of the Atlas facility is shown in Fig. 1.

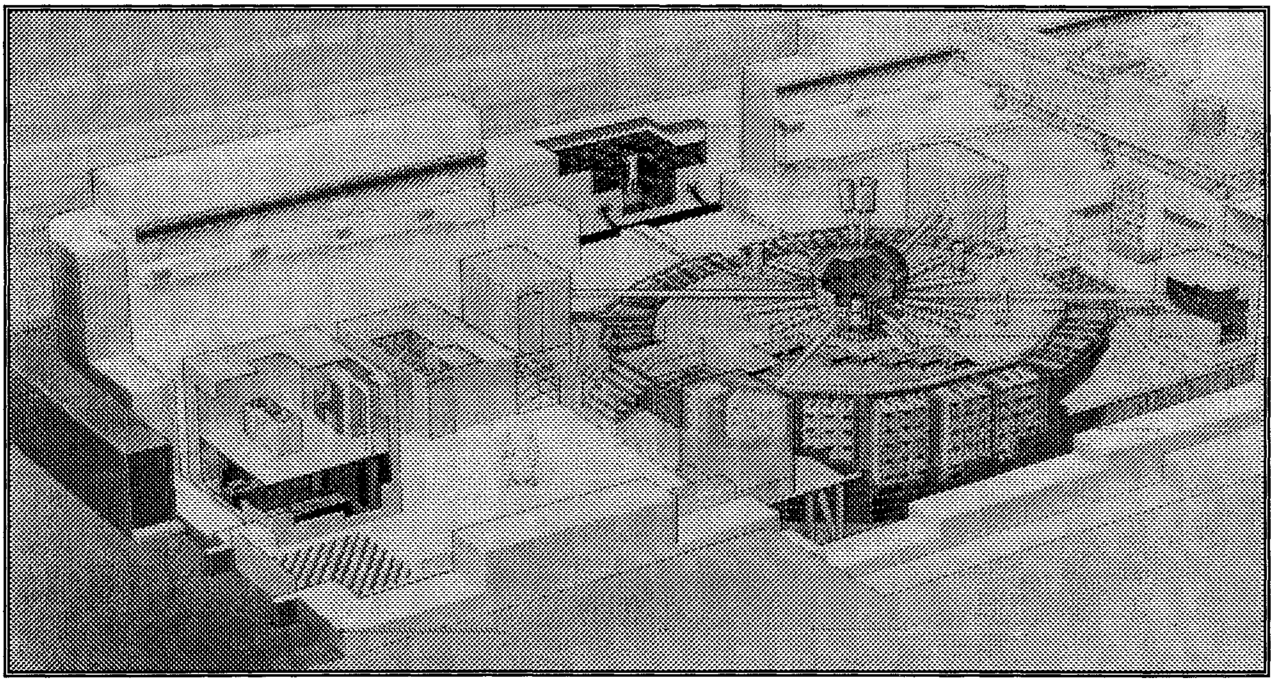


Fig. 1 Artist's conception of the Atlas facility.

The conceptual design of the Atlas system has three major subsystems; the capacitor bank, the target chamber, and the capacitor charging system. An overview of these subsystems, and how each addresses the design requirements, is presented in the following sections.

Capacitor Bank

Capacitors. Medium and high energy-density capacitor technologies were examined for use in the Atlas design. The medium energy-density design was based on 60% voltage-reversal, 7.5-kJ capacitors. For a 25 MA output with a 2 - 3 μs rise time, 1920 capacitors totaling 14.4-MJ would be required. This design had two problems. First, the capacitors would not easily fit into the facility available for Atlas construction. Second, projected fault currents in this design were extremely high, and the résultant damage to spark gaps and areas adjacent to the fault would likely cause unacceptable delays in the test schedule.

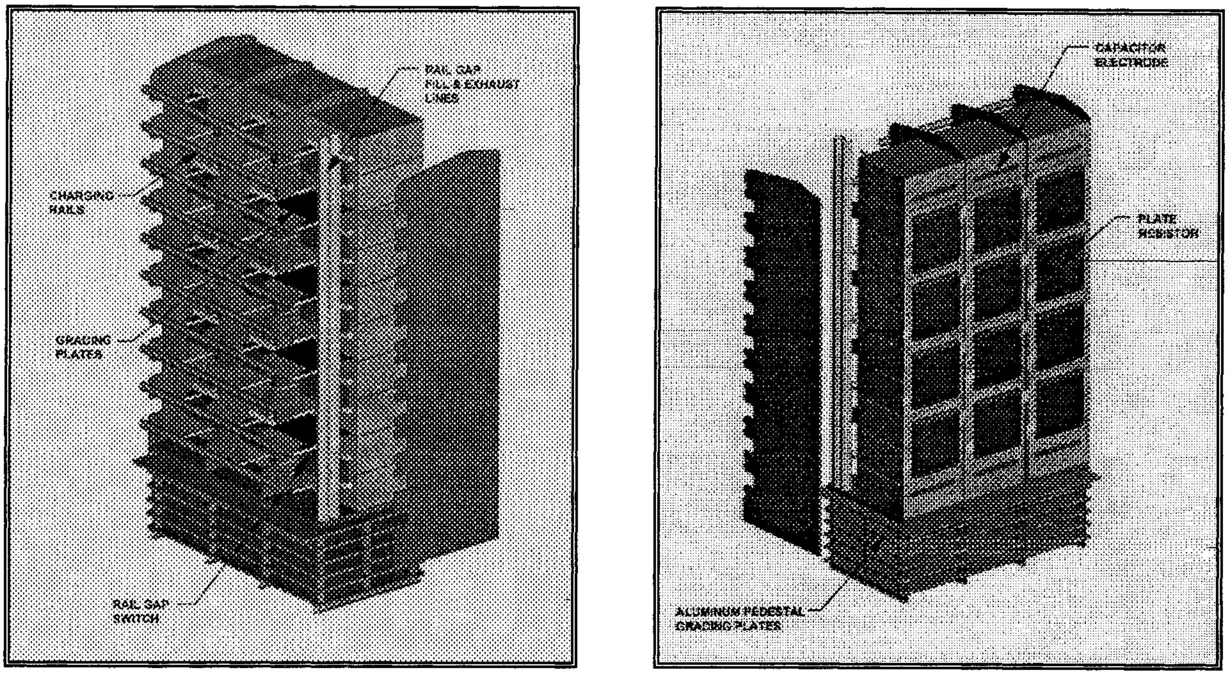
The high energy-density design was based on 20% voltage-reversal, 30-kJ capacitors. The design includes a damping resistor in series with each of 1200 capacitors, yielding a total stored energy of 36 MJ. The damping resistors prevent the bank voltage from reversing beyond its rating. This design has two important advantages. First, the capacitors occupy less space than the medium energy-density design and readily fit into the available facility. Second, under fault conditions, the damping resistors limit spark-gap current and charge-transfer to non-destructive levels. Table III compares normal operating levels to fault conditions for both designs. Because of the advantages afforded by the high energy-density design, it was chosen as the preferred option for Atlas.

Table III. Normal Operating Levels vs. Fault Conditions

	Normal Operating Levels*	Fault Condition Comparison	
Capacitor type		Medium-density	High-density
Spark-gap current (kA)	416	920	720
Spark-gap charge transfer (coul.)	2.0	43	2.4
Arc energy (MJ)	n/a	2.30	1.05

* Based on full-current discharge of 25 MA

Marx Modules. The present conceptual design for an Atlas Marx module[7] is based on a capacitor case style known as the *Fastcap*[8,9] configuration. The 60-kJ (2 ea, 30-kJ units in parallel) capacitors are plastic-cased and rated for 60 kV. The *Fastcap* design, combined with modified Maxwell railgaps[9] and plate-type resistors,[10] provides a low-inductance configuration with a minimum number of parts. The present design is air insulated, but can easily be adapted to oil-insulation if necessary. A 1.8-MJ Marx module, composed of three submodules is shown in Fig. 2.



(a) (b)

Fig. 2 Atlas Marx module
(a) Front view
(b) Rear view

Operation. The system operates as follows: Alternate capacitors are precharged to $\pm$ 60 kV. When the railgap switches on the front of each module are triggered, the individual stages are connected in series and the Marx modules "erect" to 600 kV. Flat-plate resistors on the rear of each module form the rest of the series circuit. The 20, parallel-connected Marx modules simultaneously discharge through a disc-type transmission line into a centrally-located load or liner. Near the load, the current density and associated magnetic fields dramatically increase. The interaction of the current and magnetic field produce Lorentz forces which implode the cylindrical liner located in the target chamber. A lightweight liner can collide with itself on axis, converting its kinetic energy into soft x-rays. A heavier liner can be used to either compress sample materials to high pressures, or when driven into a central target, produce extremely high shock pressures.

Target Chamber

The present design of the target chamber has walls that are sufficiently far from the target for the chamber to survive intact from the shrapnel and debris of the discharge. This requirement is mandated to achieve the maximum anticipated shot rate of 100 per year. The approximate overall dimensions of a chamber meeting these requirements is 10 ft in diameter. Fig. 3 illustrates the conceptual design of the Atlas target chamber.

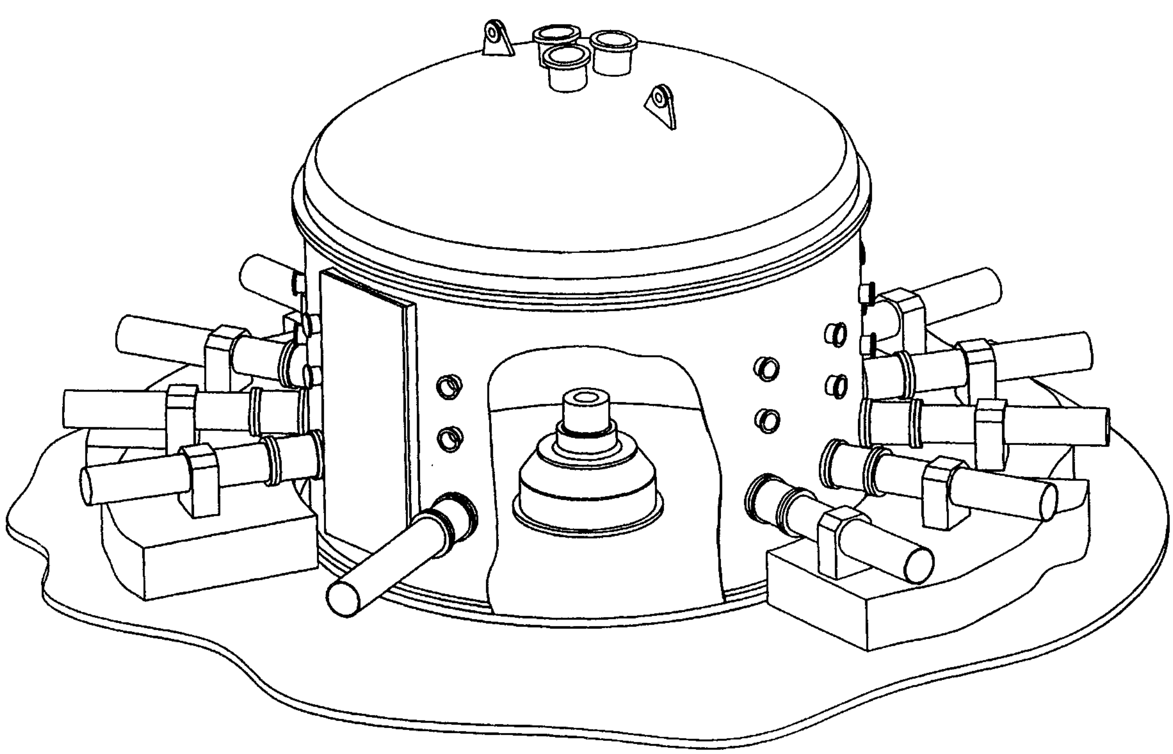


Fig. 3 Conceptual design of Atlas target chamber

Present estimates indicate more than 12 MJ will be trapped and dissipated in the target chamber when the vacuum insulator crowbars from the Poynting vector changing direction. Because of the variety of anticipated experiments, a high degree of flexible diagnostic access is necessary. Diagnostic access for end-on views of the target will be available. Radial access in the target plane is critical. Several in-line port pairs for diagnostics that involve active backlighting with visible light or x-rays will be available. The large chamber dimensions necessitate re-entrant port capability for those diagnostics that require high flux. The target chamber will also contain an internal platform structure for personnel involved with diagnostic alignment.

Charging System

The railgap switch is extensively used in the Shiva Star facility[11] (144 units). The present design for Atlas uses 300 of these switches. Since an inadvertent prefire of a railgap switch is the most likely failure mode, reliable operation of the railgaps is critical for Atlas to achieve an overall system reliability greater than 95%. Based on the assumption that prefire probability is generally proportional to the time a switch has to withstand voltage, an R&D program has been initiated to measure railgap prefire rates as a function of capacitor charging time. Conventional rectifiers connected to the grid could be used to charge the Atlas capacitor bank in the 6 - 60 s range, if switch tests indicate that the long charging times can be tolerated. A more conservative approach will use a large rectifier connected to a nearby 1430-MVA generator.[12] This combination will be able to charge the bank in the 1 - 6 s range. If faster charging is required to prevent prefire, an inductive storage and transfer system will be utilized.

The inductive storage and transfer system has been conceptually designed and will be capable of charging the Atlas capacitor bank in 40 milliseconds. Several electrical stages will be used to obtain time-energy compression. Fig. 4 is a block diagram of this energy-compression scheme.

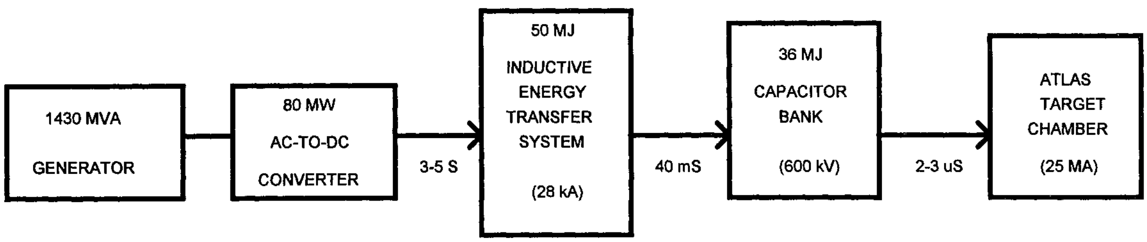


Fig. 4 Energy compression scheme for 40 ms bank charging

Line power will be used to spin the 1430-MVA motor-generator to 1800 rpm in approximately 20 minutes. The motor-generator will then be switched to an 80-MW ac-to-dc converter which will charge an existing 50-MJ inductor to 28 kA in 3 - 5 seconds. When the inductor is

switched into the capacitor bank, it will charge the bank to ± 60 kV in 40 milliseconds. The railgap switches would then be immediately triggered, minimizing their voltage hold-off time and reducing the probability of a spurious prefire.

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